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THREAT PERCEPTION WHILE VIEWING SINGLE INTRUDER CONFLICTS ON A COCKPIT DISPLAY OF TRAFFIC INFORMATION

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SUMMARY

Subjective estimates of the threat posed by a single intruder aircraft were determined by showing pilots photographs of a cockpit display of traffic information. The time the intruder was away from the point of minimum separation was found to be the major determinant of the perception of threat. When asked to choose a maneuver to reduce the conflict, pilots selected maneuvers with a bias toward those that would have kept the intruders in sight had they been visible out the cockpit window.

INTRODUCTION

Contemporary advances in ground and cockpit based avionics have made possible the placement of electronic displays of air traffic information in aircraft cockpits (Wempe, 1974). These advances, accordingly raise many questions as to how pilots will use this type of information and how their use will affect existing air traffic control procedures (Verstynen, 1980).

The traffic information may, for example, allow pilots to assume some responsibility for maintaining safe spacing from other aircraft under conditions which presently would require assistance from ATC (Connelly, 1977; Chappell and Palmer, 1981). Uses such as this assume that the information displayed to pilots will enable them to detect incipient threatening situations and to take actions to prevent potential threats from becoming truly dangerous situations. This assumption, however, must be tested since it is not known, *a priori*, that pilots will be able to detect potential threats in a timely manner with acceptable workload levels and respond with appropriate actions.

Thus, it is important to try to determine what may be called the pilots' "subjective threat avoidance logic" when viewing a CDTI, in order to help assess what new procedures, if any, the installation of such equipment may enable. It is, for example, important to assess whether the pilot's "threat logic" is compatible with that of the ground controllers or that of automatic collision avoidance systems.

Previous experiments concerning pilots' ability to use CDTI to determine the future relative position of intruding aircraft have suggested that this task may be quite difficult (Stark and Ellis, 1981; Palmer, Jago, and Baty, 1980). Accordingly, the use of CDTI will probably require automatic assistance of the sort provided by Automatic Traffic Advisory Resolution Service (ATARS)-type conflict alerts (Lentz et al., 1980). The interaction of automatic conflict alerts with CDTI, however, provides another potential problem since the actions suggested by the alerts may conflict with those chosen by a pilot viewing the CDTI. Thus, the presence of CDTI in the cockpit may substantially affect the pilot's reaction time to the alerts.

Another consideration for the introduction of CDTI-type information augmented by automatic alerting systems regards pilot acceptance of such an instrument. An instrument which frequently leads to incorrect or unnecessary pilot perceptions of traffic conflicts can hardly be expected to win pilot approval. Training and experience, of course, may lead to eventual acceptance; however, the training necessary is undoubtedly related to the bias pilots bring to its use. Furthermore, in order to insure that its use will be predictable and not break down under conditions of stress or high workload, the design of the decision logic and display characteristics of the system should conform, as much as possible, to the preexisting biases users bring to the system.

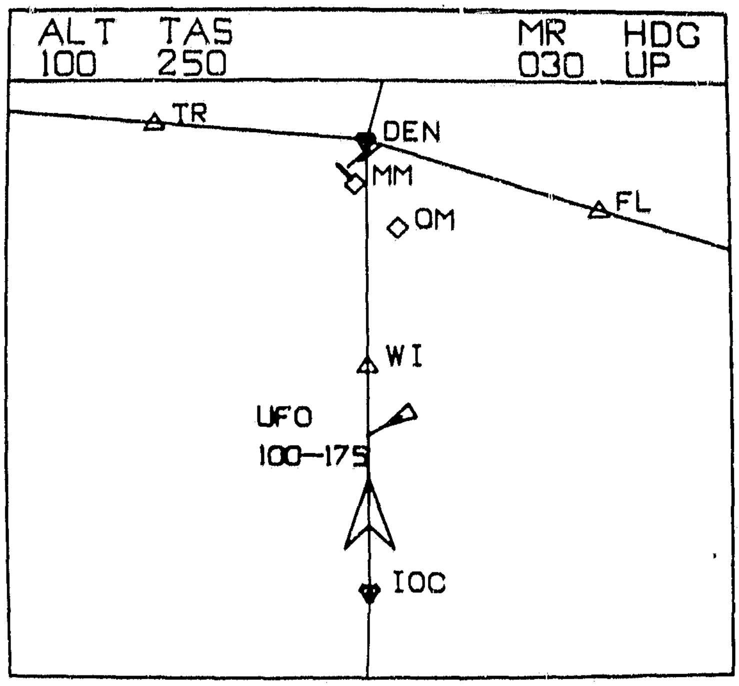
The most realistic assessment of the potential use of CDTI is, of course, through full mission simulation and flight testing. These research techniques are, however, costly and preclude the systematic examination of the experimental conditions generated by even relatively small factorial experimental designs. Accordingly, part-task experimental designs are required to help select display systems for more realistic experiments in simulators and aircraft. The following study is one of a series of part-task experiments designed to run in parallel with part and full mission simulations currently examining related questions regarding the use of CDTI (Chappell and Palmer, 1981).

METHOD

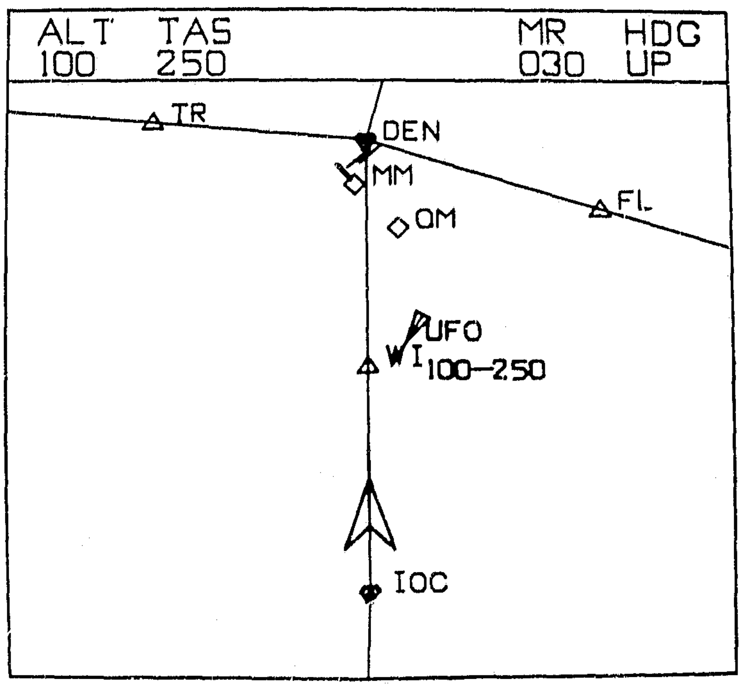
Generation of the Display

Generic CDTI displays were produced using an Evans and Southerland calligraphic Picture System controlled by a PDP-11/40 computer. The general format of the display was derived from that used in previous experiments (Palmer et al., 1980; Hart and Loomis, 1980). A photograph of two of the displays is shown in figure 1 which depicts ownship on nominal approaches to runway 26L at Denver Stapleton International Airport. Ownship position is represented as the tip of the chevron two-thirds of the way down from the top of the display. As in previous experiments (Palmer et al., 1980), the aircraft symbol is augmented by a straight, solid 32 sec predictor and dotted line showing 32 sec of history. Ownship barometric altitude in hundreds of feet and ground speed in knots were shown in the upper left of the display. The current map range from ownship to the top of the map, shown as 30 n. mi., and the mode of the display, heading up, were shown in the upper right corner. The distance from ownship position to the airport was approximately 30 n. mi. A single intruding aircraft was represented at ownship's altitude as the apex of a triangle on each display and augmented with a similar 32 sec predictor and history. The intruder's data tag included the identification "UFO" and two numbers, the left representing barometric altitude in hundreds of feet and the right representing true airspeed in knots. These above characteristics and the background map remained constant for all the static displays that were generated. The choice of map range was based on discussions with several pilots who normally fly into Denver along this approach route.

A four factor central composite design (Clark and Williges, 1973) was used to examine the effects of varying the intruder's minimum separation (0, ±0.5,



(a) Mean subjective threat (rank) = 18.0, mean subjective threat (rating) = 7.5, minimum horizontal separation = 0.5 n. mi., time to minimum separation = 40 sec.



(b) Mean subjective threat (rank) = 7.7, mean subjective threat (rating) = 4.4, minimum horizontal separation = 1.0 n. mi., time to minimum separation = 80 sec.

Figure 1.- Sample traffic conflicts with low perceived threat.

±1.0 n. mi.), time to minimum separation (20, 40, 60, 80 sec),[1] relative velocity (0, ±75, ±150 knots), and relative heading (±30, ±60, ±90°). Once the complete set of encounters were generated, they were displayed on the Picture System scopes and photographed (see fig. 1) so that high contrast 8×10 prints could be prepared. Photographs were used for the experiment because previous results suggested that neither update rate nor total time viewing developing conflict affects estimates of future intruding aircraft position (Palmer et al., 1980). These findings are consistent with the observation that a CDTI which is updated every 4 sec is an essentially static display.

Procedure

The experiment was conducted in a small conference room with a table on which the photographs were placed. The pilot opinions regarding the encounters were collected after pilots read a small briefing book (see appendix) explaining the display symbology, scenario assumptions, and threat rating technique. Two different techniques were used. In method A, the pilots sorted a randomly shuffled stack of 25 photographs as to the degree of collision threat caused by the intruder. No specific sorting technique was recommended, but all the subjects independently chose first to divide the stack into several smaller stacks and then to sort the smaller stacks. In method B, the pilots were given another stack of 25 photographs which were mirror images of those in the first stack. For each photograph they were to rate the threat of collision in terms of what action they felt they would have to take in the depicted situation. The two traffic situations illustrated in fig. 1 show sample mean threat ranking and rating. The rating scale was expressed in terms of the relative urgency of an avoidance maneuver; for example, a rating of 0 indicated the intruder could be ignored, a rating of 4 indicated a maneuver needed within 30 sec, and a rating of 10 indicated a maneuver was overdue (see appendix). After the pilots selected a rating, they chose a maneuver that they thought appropriate from a matrix of nine options, including that of no maneuver:

climb left	climb	climb right
left	none	right
descend left	descend	descend right

Pilots were run in pairs so that while one was using method A the other was using method B; after completing the first rating technique the pilots switched methods. Thus, the order of rating techniques was counterbalanced across subjects, and all pilots used both techniques. Discussion of the encounters was limited to questions before and after the actual rating and sorting took place. After completing the two evaluation techniques, the pilots were debriefed regarding their previous experience with CDTI experiments at Ames and their experience with flights to Denver.

[1] A fifth value of 100 sec for time to minimum separation was accidently omitted. Its omission only affects two of the 25 traffic conditions presented to each subject and reduces the statistical power of tests on the miss distance variable and all of its interactions. Since no tests of interactions were planned, this omission has a negligible effect on the interpretation of the results.

Subjects

Ten line-qualified airline pilots participated in the experiment. Since all worked for major air carriers flying out of Denver, all had substantial experience flying there. Seven had previous experience with CDTI experiments, though none had to make threat ratings previously.

RESULTS

The subjective threat data were collected in two different ways to allow comparison of different dependent measures. The dependent variables used were: the rank of the threat from method A and the rating of the threat from method B. These variables were each checked for intersubject agreement by calculating Kendall's W with correction for ties (Siegel, 1956). All three showed highly statistically significant intersubject agreement:

$$\text{Rank from sorting:} \quad W = 0.571 \,, \qquad p. < 0.001$$

$$\text{Rating:} \quad W = 0.470 \,, \qquad p. < 0.001$$ [2]

However, the values of W show that the pilots were less than unanimous in their threat perceptions of the different encounters. Thus, the remaining analyses were conducted on a subject-by-subject basis, through some graphs show pooled data.

Multiple regressions testing only for linear main effects were calculated separately for each subject in the manner of central composite designs (Clark and Williges, 1973; also see Curry, 1977). In addition to the independent variables of minimum separation, time to minimum separation, relative speed, and heading, the algebraic sign of minimum separation and heading were coded as independent variables having values of ± 1. In order to separate these two "sign variables" from the parent variables from which they were derived, only the absolute value of the parent variables, minimum separation and heading, were used for the regression equation.

These "sign variables" were intended to help determine whether the direction of the parent variables rather than their magnitude had an effect on subjective threat. A positive minimum separation corresponded to passage of the intruder in front of ownship while a negative value corresponded to passage behind. If all aircraft passing in front were perceived, for example, as more threatening than aircraft passing behind, and this perception were unrelated to the absolute magnitude of miss distance, then the sign of minimum separation would contribute to the prediction of subjective threat while the absolute value of minimum separation would not. An analogous argument can be made with respect to heading and its sign since positive values of heading indicate intruding aircraft coming from the left and negative values indicate aircraft from the right.

Thus, the multiple regression equations used to predict the subjective threat ranking and threat rating for each subject were:

[2]For data with no ties the W is proportional to the mean of all the pairwise Spearman rank order correlations between the variables. A value of 1.0 represents perfect ordinal agreement among the subjects, 0 represents maximum disagreement.

$$T(rank) = a1(sms) + a2(sh) + a3(ms) + a4(tms) + a5(h) + a6(rs) + a0$$

$$T(rate) = a1(sms) + a2(sh) + a3(ms) + a4(tms) + a5(h) + a6(rs) + a0$$

where t(rank) and t(rate) are subjective threat estimated by sorting or rating, respectively, sms is sign of minimum separation, sh is sign of heading, ms is minimum separation, tms is time to minimum separation, h is heading, and rs is relative speed.

As tables 1 and 2 show, the independent variable showing the most repeated statistical significance and a consistent direction of effect across subjects was time to minimum separation, which in our encounter situation is similar to horizontal tau (range divided by range rate). The negative value of the regression coefficient for time to minimum separation indicates that subjective threat decreases as time to minimum separation increases.

TABLE 1.- RANKING FROM SORTING FOR SUBJECTIVE THREAT

Subj.	Mult. R	Stand. err. of reg.	Coefficients of regression variables						Const. of reg.
			Sign of min. separation	Sign of heading	Min. separation	Time to min. separation	Heading	Relative speed	
1	0.90	3.66	ns	ns	-15.03[a]	-0.24[c]	-0.12[c]	ns	1.92
2	.77	5.42	↓	↓	-11.47[c]	ns	-.11[c]	↓	3.75
3	.93	3.11	↓	↓	ns	-.31[c]	ns	↓	5.33
4	.90	2.66	↓	↓	↓	-.28[c]	↓	↓	12.70
5	.75	5.58	↓	↓	↓	-.20[c]	↓	↓	10.61
6	.57	6.94	↓	↓	↓	ns	↓	↓	.02
7	.94	2.93	↓	↓	↓	-.29[c]	↓	↓	10.44
8	.94	2.93	↓	↓	↓	-.28[c]	↓	-9.04[b]	14.46
9	.93	3.09	↓	↓	↓	-.29[b]	↓	ns	4.92
10	.71	5.98	↓	↓	↓	-.38[c]	↓	ns	-.71

ns: not significant

[a]p. < 0.05
[b]p. < 0.025
[c]p. < 0.01

This relationship between time to minimum separation and subjective threat is shown in figure 2 where the mean values of the dependent variables are plotted showing a strong linear trend. The reliability of the effect shown in this figure was checked with Friedman analyses of variance (Siegel, 1956) for each of the methods of assessing subjective threat.

Threat from sorting: chi-square(r) = 23.88, df = 3, $p < 0.001$

Threat from rating: chi-square(r) = 16.44, df = 3, $p < 0.001$

The other terms of the regression show only spotty and inconsistent effects across subjects. For example, a negative coefficient for the minimum separation term

TABLE 2.- RATING OF SUBJECTIVE THREAT

Subj.	Mult. R	Stand. err. of reg.	Coefficients of regression variables						Const. of reg.
			Sign of min. separation	Sign of heading	Min. separation	Time to min. separation	Heading	Relative speed	
1	0.70	1.55	ns	ns	ns	-0.04^{c}	ns	ns	8.76
2	.61	1.93				$-.04^{c}$	ns		6.85
3	.85	1.11				$-.06^{c}$	ns		11.10
4	.92	1.04				$-.09^{c}$	-0.03^{c}		12.31
5	.62	1.73				$-.04^{a}$	ns		7.55
6	.70	1.41				$-.04^{c}$			6.62
7	.45	1.95				ns			4.24
8	.96	.96				$-.07^{b}$			8.62
9	.85	1.39				$-.08^{b}$			11.11
10	.72	.45			-0.78^{a}	$-.01^{c}$			9.30

ns: not significant

[a] p. < 0.05
[b] p. < 0.025
[c] p. < 0.01

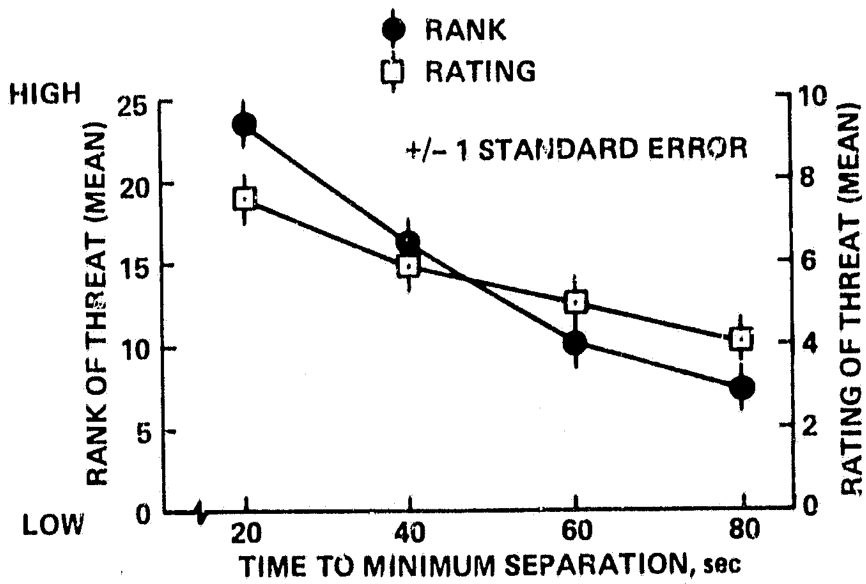


Figure 2.- Perceived threat as a function of time to minimum separation.

indicates that intruders passing farther away were perceived as less threatening. This coefficient is negative and statistically significant for only one or two subjects, but the specific subjects showing statistical significance depend upon which method of assessing subjective threat is used. Similarly, though a negative coefficient for the heading term would indicate that a more head-on intruder would seem less threatening than one coming more from the side or from behind, this coefficient reached statistical significance for only two subjects. Furthermore, the direction of effect was inconsistent since the sign of the coefficient was both positive and negative depending upon the subject.

The pilots' selections of maneuvers were analyzed with respect to the matrix of options described in the briefing book with the exception that all turning maneuvers were mapped into categories of turning toward or away from the intruder. Collapsing all subjects together produces table 3, which shows that pilots have a tendency to turn toward or descend with respect to the intruder, but that there is no evidence of interaction; that is, the number of composite maneuvers, such as descending turns, is not disproportionately large.

TABLE 3.- BREAKDOWN OF NUMBERS OF CHOSEN MANEUVERS
(collapsed across subjects)

	Toward		Away	Totals
Climbing	20 climbing toward	25 climbing	8 climbing away	53
	29 toward	20 none	11 away	60
Descending	57 descending toward	54 descending	16 descending away	127
Totals	106	99	35	240

Chi-square = 2.760, $p. \leq 0.50$ ns

The tendency to turn toward the intruding aircraft may be expressed as a pair of counts for each pilot. The first count is the total number of maneuvers classified as turns toward, that is, the sum of climbing-turns toward, level-turns toward, and descending-turns toward. The second count is the total number analogously classified as turns away. One may use these pairs to test both the direction and magnitude of the preference for each pilot. Since previous experiments have suggested the existence of a bias to turn toward the intruding aircraft (Palmer et al., 1981), a one-tailed test for a similar bias may be justified. The tendency to turn toward the intruding aircraft occurs in seven of ten pilots; the two remaining pilots showed no turning preference. A sign test across subjects on this preference show it to be marginally reliable (sign test: $p. < 0.035$, one-tailed, but $p. < 0.07$, two-tailed). The within-subject sign tests show that only five of the ten subjects exhibited reliable biases to turn toward the intruder. Therefore, although this within-subject analysis may not be very powerful due to the relatively small number of maneuvers analyzed, the bias may not be representative of the entire pilot population. Future experiments will allow an increase in the size of the sample of pilots and the number of maneuvers, and should allow a more statistically powerful assessment of the bias.

TABLE 4.- MANEUVER PREFERENCES FOR EACH SUBJECT

Subjects	Turns toward	Turns away	Climbs	Descents	Maneuvers keeping intruder in sight	Maneuvers not keeping intruder in sight
1	21	0^{c}	0	3	24	0^{c}
2	8	0^{c}	0	2	10	0^{c}
3	21	1^{c}	0	22^{c}	21	1^{c}
4	11	11	5	14	12	12
5	14	0^{c}	11	4	11	11
6	16	0^{c}	19	0^{c}	3	19
7	6	11	8	8	10	14
8	0	0	10	14	14	10
9	12	7	0	5	17	7
10	2	0	0	24^{c}	24	0^{c}

[a] $p. < 0.05$
[b] $p. < 0.025$
[c] $p. < 0.01$

A similar method can be used to determine each subject's preference of vertical maneuvers, but for this case a one-tailed test may not be justified by previous results. Of the nine subjects exhibiting a preferred direction of vertical maneuver, seven show a preference for descending maneuvers; only one subject chose an equal number of ascending and descending maneuvers. Thus, the tendency to descend does not stand up as reliably across subjects as the tendency to turn toward the intruding aircraft (sign test: $p. < 0.09$, one-tailed, $p. < 0.18$, two-tailed).

Since discussions with the pilots after the experiment indicated that their choice of maneuver may have been motivated by the desire to keep the intruder potentially "in sight," maneuvers for each pilot were classified as (1) those that would keep the intruder "in sight" and (2) those that would not. Because all intruders were at ownship's altitude, any maneuver incorporating either a climb or turn away could be considered one that would not keep it "in sight." Thus, only descents, turns toward, and descents toward would keep the intruder "in sight." Since there are three cells for "in sight" maneuvers and five cells for "not in sight" maneuvers and the null hypothesis assumes equal number of maneuvers per cell, a bias to maneuver so as to keep the intruder in sight would manifest itself by a ratio of "in sight"/"not in sight" exceeding 3/5. Nine of the ten subjects show such a ratio (binomial test: $p. < 0.028$, two-tailed). However, this result should be tempered by the observation that within-subject chi-square tests of each subject's "in sight"/"not in sight" ratios show only four subjects with reliable biases.

DISCUSSION

The dominance of time to minimum separation as a factor influencing "subjective threat" is an interesting finding since the related measure, tau or range/range rate, is an important factor included in automatic alarm systems (Lenz et al., 1980). The pilot's choices of maneuvers, however, are not congruent with the avoidance maneuvers typically recommended by these logics. The automatic systems often chose maneuvers

that will maximize minimum separation, which in the horizontal case usually involves a turn away rather than a turn toward an intruder (Palmer, Jago, and DuBord, 1981).

The choice of the turns toward intruders, as well as the descents, may have been caused by the pilots' disposition to maneuver so as to keep the intruder potentially in sight. Several of the pilots mentioned this fact spontaneously in their debriefing. In fact, the description of their maneuvers as turns toward the intruding aircraft is not completely general, since they were actually attempting to turn so as to go behind the intruder, a maneuver that has the effect of minimizing time to resolve the traffic conflict. Nevertheless, their choice is especially interesting since all subjects were told to assume IMC conditions and that they therefore could not expect to be able to see the intruder out the window.[3]

A number of display conditions used for this experiment may have affected the results in specific ways. The choice of a 30 n. mi. map range, for example, may have made the display of the miss distances of 0.5 and 1.0 n. mi. appear as relatively indiscriminable distances. This display condition could have reduced the influence of minimum miss distance in determining subjective threat. Similarly, the choice of a scenario in which the pilot was cleared for an approach to Denver may have influenced the use of vertical evasive maneuvers: the pilots may have had the presumption that airspace below them was available.

The choice of the ranges of each of the experimental variables was, however, made to cover a "range of concern" in an attempt to examine situations where the "subjective threat judgment" of the pilots might be an important issue in the resolution of a dangerous conflict. Thus, attempt to maximize the power of any examination of encounter parameter was temporized by an attempt to keep the display situations realistic and relevant toward the use of CDTI in actual traffic situations.

Subsequent experiments will investigate some of the biases and effects discussed here as well as their interactions. Specific factors to be investigated will be the effect on subjective threat of the choice of different map ranges, the choice of a departing rather than arriving scenario, the effect of traffic at different altitudes with either closing or diverging vertical speed, and the influence of the predictor types.

ACKNOWLEDGMENT

We wish to acknowledge the assistance of Terry Dunley in the collection of the data and its initial analysis.

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[3]Note that the resistance to training of this maneuvering is not addressed by this experiment.

APPENDIX

COCKPIT DISPLAY OF TRAFFIC INFORMATION

INTRODUCTION

The photographs of Cockpit Display of Traffic Information (CDTI) present encounters with intruding aircraft of various levels of threat. The purpose of the experiment is to assess the subjective dimensions of threat. Encounters presented vary in several objective dimensions such as miss distance, time to minimum miss distance, relative velocity, and approach angle.

These parameters enter into the decision logic of potential collision avoidance systems and we wish to determine if these systems make decisions consistent with the pilots' perceived level of threat. The specific encounters we will present are somewhat arbitrary and you should consider the intruder a "Maverick" who is not part of an approach pattern and who will continue his current flightpath.

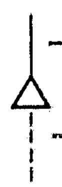
SYMBOLOGIES

OWNSHIP:

32 sec flightpath predictor

NOTE: If ownship were in a 3°/sec turn its predictor would look like this:

INTRUDER:



32 sec flightpath predictor

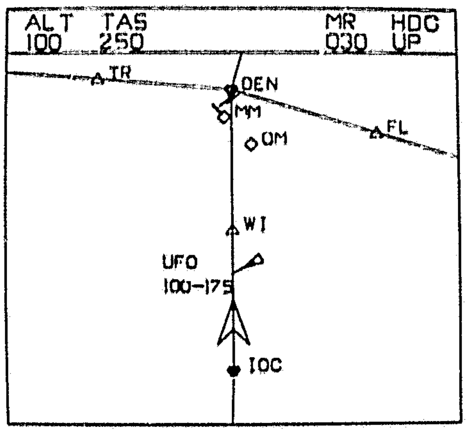
32 sec flightpath history

UFO → data tag
XXX-YYY

XXX — Barometric Altitude (ALT), measured in hundreds of feet (i.e., 100 corresponds to 10,000)
YYY — True Air Speed (TAS), measured in knots per hour

NOTE: Actual positions of the aircraft are at the tip of the symbols that represent them.

DISPLAY CONSOLE:



MR 30 miles

NOTE: Assume intruder continues at current heading, speed, and altitude for the individual encounters.

NOTE: Ownship speed and altitude are indicated as being the same in all photographs; these as well as heading could be changed.

SOME ADDITIONAL ASSUMPTIONS:

Assume IMC conditions (i.e., you can't visually see other aircraft).

Assume intruder has a transponder but no CAS or CDTI system (i.e., intruder doesn't see you).

Assume cleared for normal approach to 26L at Denver Stapleton Airport.

MR (Map Range) — Measured from ownship to top of display
HDG (Heading) — Heading indicator, no wind: track UP

Navigation points:

MM, OM — Middle/Outer Marker
WI — Way point
IOC — VOR/DME

INSTRUCTIONS — EXPERIMENT A

With the given photographs of 25 possible encounters, evaluate and sort all 25 as to the degree of collision threat that you feel is caused by the intruder aircraft. Order the photos in a stack using the following scale as a guideline:

Arranged order	Degree of threat
Top of stack	Critically high
	Very high
	High
	Medium
Bottom of stack	Low

INSTRUCTIONS — EXPERIMENT B

This experiment has two parts for each photo:

1) Rate the degree of action.
2) Select a maneuver you would be inclined to use.

PART 1:

The given 25 displays of possible encounters have varying degrees of threat of collision. Evaluate each of the 25 displays according to degree of action you feel would need to be taken to avoid collision. Rate the displays individually by selecting a degree of action number (DA #) between 0.0 and 10.0 that you feel represents the course of action needed. Use the following scale as a guideline:

DA #	Degree of action
0.0	Ignore
2.0	Continue monitoring
4.0	Possible evasive (maneuver likely within the next 30 sec)
6.0	Probable evasive (maneuver likely within the next 15 sec)
8.0	Immediate evasive (maneuver right now)
10.0	Violent evasive (should have maneuvered sooner)

NOTE: You may select any DA # (0.0-10.0) to represent the degree you feel is necessary (i.e., 5.0, 5.4, 5.6, 7.0, 7.2, etc.).

PART 2:

As you also rate the encounters individually, select a maneuver for each that you feel you might do in order to decrease the threat of collision. Use the figure below as a guide for the maneuvers you would make:

Climb Left	Climb	Climb Right
Left	None	Right
Descend Left	Descend	Descend Right

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